PREDICTION TECHNIQUE FOR OVERPRESSURE AND THERMAL RISK FROM C/D 1.3 MATERIALS DURING PROCESSING

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ABSTRACT

Manufacturing and processing of propellants and pyrotechnics which will deflagrate but not detonate creates a unique safety risk to personnel involved in these operations. Determination of safe distances for operators from processing has been based on past experience, empirical judgment or just guesswork. With advances in computational tools and desktop computers, a more reliable and accurate method is available. This paper discusses a technique which will have widespread application in the future and greatly enhance safety in C/D 1.3 operations.

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Introduction

The nature of the expected performance of ammunition and explosives within the Department of Defense (DoD) is defined by a classification system which is the basis for U.S. ammunition safety regulations. The method defines each munitions item or processing activity by class and division. The following definitions are of interest for this paper:

- Class/ Division 1.1
- Class/Division 1.2
- Class/Division 1.3

Munitions or activities categorized as C/D 1.4 and higher represent relatively low risk because of the nature of these munitions or their energetic content and are not discussed further for that reason. Initiation of Class/Division 1.1 and 1.2 materials result in detonation wave velocities within the explosive material and resulting energy transfers described in classical explosive shock physics in air. Class/Division 1.3 materials are those that typically perform in such a manner where if unconfined, the velocity of the propagation wave in an energetic reaction within the material will not reach detonation velocity. Each classification has associated with it certain quantity distance criteria and other safety requirements to approximate an acceptable risk and level of safety. The derivation of these safety criteria have resulted from research, study of the consequences of accidents, experiences of personnel in the operations and safety community, and policy decisions within the regulatory agencies over time.

Background

The consequences of Class/Division 1.1 events, i.e. actual detonation, is so dominating with regard to risk to personnel and assets, that the preponderance of all research testing in the last fifty years has been concentrated in that area. As a result we are, with increasing confidence and accuracy, able to define and predict the consequences of

classical detonation events in terms of shock pressure, gas pressure and thermal environment. On the other hand , defining the consequences of Class/Division 1.3 events, or generically, deflagration has received much less attention. As a result, much of the current safety guidance for these materials, particularly while in the manufacturing process, is approximate, and difficult or impossible to use in determining realistic hazards and risks to personnel. Accidents continue to occur while processing C/D 1.3 energetic which demonstrate both our lack of basic understanding of the initiating events, and the inconsistent nature of past experience as a guide to establishing operating procedures. Recent advances in computational analysis tools, correlated with several test programs have provided an initial capability to overcome some of these historical shortcomings.

Historical Analytical Methods

Analysis of the propagation of shock, deflagration and thermal energy in an energetic material is an extremely complex problem. Classical equations of physics and chemistry can provide such predictions under only the most restrictive conditions [1, 2]. The use of classical solutions is limited by the two primary factors: the rapid change in the properties of the initiating material and surrounding air with time , and the modification of the expanding gas material by interaction with surrounding objects or structures. These factors have historically limited the ability to rationally estimate meaningful blast environments and quantity distances for C/D 1.3 materials in typical operating or storage facilities. As a result of these problems. Empirical rules derived form experience have been used to develop safety controls for 1.3 materials. Examples are the use of "vent panels" to control internal pressure build-up and fire walls and doors to protect workers from thermal exposure. As accidents have occurred, observations of consequences have been used to generate quantity distance rules of thumbs. The applicability of these rules is very sensitive to the similarity in facility or storage structure configuration compared to the source of the original observation.

Hydrodynamic Computational Methods

The problems and limitations on methods of calculations described are identical to those faced by analyst involved in defining the blast shock and thermal environment from nuclear weapons. The importance of predicting the nuclear environment to define survivability was a critical area of national defense. Within the U.S. this led to extensive research and testing to develop analytical tools capable of defining the airblast environment. U.S. National laboratories developed hydrodynamic computational codes which provided the ability to predict the airblast environment. These methods incorporated first principle laws of physics and chemistry into computer codes which defined the physical state of small finite elements of the expanding energetic and surrounding gas medium and analyzed the state of the material elements at progressive, very small time steps. These codes are enormously computation intensive. As a result for many years the ability to solve these problems required access to very powerful supercomputers. However in the last few years the cost of computing power has dropped enormously. A desktop personal computer now has significant capability. In addition, simplified versions of the highly sophisticated hydrocodes have become commercially available for operation on commonly available robust desktop computers. These advances in technology have now provided a powerful tool which has the capability of provide far superior capability in evaluating the consequences of an energetic event such as a C/D 1.3 deflagration.

Next, an example is included using the hydrocode AUTODYN2D. We are interested in obtaining not only the variation of temperature but also the variation of Internal Energy at each target point. This will help to follow the displacement of the fire ball and the damage occasioned to its step. This is important since the safety standard establishes that personnel be protected from the thermal effects of an accidental explosion. Protection shall be provided such that the personnel are exposed to thermal fluxes less than 0.3 calories/cm4^2/second. Fluxes can be obtained using the Internal energy vs. time and temperature vs. time curves with the area perpendicular to the flux lines at the point of interest (target point).

ANALYSIS

Numerical Modeling

The facility considered in this example is shown in Figure 1. Thirteen target points at which data vs. time was saved, are shown also in figure 1. An accidental explosion is assumed to take place in the bay with the circle, just in front of target point 1. The units used are millimeter, milligram and millisecond for the basic three dimensions. The equivalent TNT load is approximate 60 pounds. This problem was run using AUTODYN2D in a Pentium-120 PC.

Due to the size of the model (approximately 20,000 cells) and to save computer time and memory, the numerical simulation has to be divided in several steps. The Euler numerical solver was used to model the example. The required modeling is essentially dependent on the dynamic behavior of the explosion/flow process; the mesh in the regions with large gradients of the parameters pertinent to the problem (e.g. shock fronts) has to be more finely defined than those regions which are of lesser interest.

The analysis was carried out in three stages. This required the use of the AUTODYN2D remap capabilities. The problem is really a one dimensional problem with spherical symmetry until the blast wave impinges on the rigid surface. At this time it becomes a two dimensional problem with axial symmetry about a vertical line through the center of the explosive. For this reason, it is possible to model the expansion of the blast wave until it reaches the rigid surface using a one dimensional model. A more detailed explanation of this process follows.

The **first step** calculates the detonation of the charge and the subsequent propagation by means of a one-dimensional wedge model with an extremely fine mesh of axysimmetric cells containing both the explosive and air. The calculation has to be halted just before the shock front reaches the closest wall. The correspondent data is then saved (frozen). After

the one dimensional model is remaped into the two dimensional model, an Ideal Gas material strength is used.

In the **second step** the stored numerical data are read in and transferred into a two dimensional axysimmetric model. This 2D model is the result of a remap operation from the frozen results taken from step 1. Then the calculation is again halted and the relevant data frozen.

In the **third step** the whole plant configuration as well as the 2D explosive model from step 2 are placed together. The new initial conditions are now the final values at the time of interruption in the second step.

This method results in improved accuracy and reduces the computer time required to complete the analysis. A fine mesh size can be used in the radial direction of the one dimensional model while still using only a fraction of the cells required in an equivalent two dimensional model.

The explosive used was TNT and a JWL Equation of State (EOS) from the AUTODYN2D material library. Air was modeled as an ideal gas. To simplify the example, rigid walls were considered. Pressures, Temperatures and Energy curves at different target points were obtained.

The changes of temperature in the near points to the explosion present big changes. This could be awarded to the tremendous changes of pressures in the area. The far away points present a softer change. It is possible that the temperature changes prediction is more accurate for points far from the explosion than near to the charge.

Model Limitations

The lack of Equations of State is a limitation to which one is faced many times in the use of hydrocodes. Although the codes have EOS libraries, these are not complete and sometimes it is difficult to find an explosive that closely matches the one in use. This results in having to make some assumptions which affect the accuracy of the final result.

In this paper TNT was used as the charge in our example. EOS for TNT is found in the AUTODYN2D library. However, EOS for explosives class C/D 1.3 are not included in the mentioned library and are difficult to find possibly because they do not exist at this time. The development of EOS is a complex process that can be done and has been done for many explosives. The development of EOS for explosives class C/D 1.3 is needed for a realistic and more accurate modeling. Obviously some testing is mandatory to validate numerical solutions. The traditional process of finding a TNT equivalent charge and then applying the hydrocode technology is not recommended due to the differences between the two types of explosives. An explosive like TNT not only has tremendous shock power but also propagates faster than an explosive class C/D 1.3 that really has no a considerable shock power.

Results:

There is a large variety of results that can be obtained from AUTODYN2D. For the present example only temperatures and internal energy are included. Figure 2 shows a typical vector velocity graph just at the beginning of the explosion (cycle 25). Figure 3 shows the same but at cycle 375. In this way the path of the fire ball can be follow. Although not included here a similar graph can be obtained showing pressures.
Figures 4, 5 and 6 show Internal Energy vs. time for target points 1, 5 and 10. Figures 7, 8 and 9 show temperature vs. time for the same set of target points. Obviously some sharp changes are evident at target points near the explosion. The tremendous variation of pressure in the area close to the explosion as well as the velocity of the blast wave affect

the initial conditions of the target points. It is clear that the temperature can be obtained for any target point at any instant.

Conclusions:

The use of hydrocodes has opened a new world of possibilities and challenges in the matter of explosions. A different type of application has been proposed here. Hydrocodes may be used to predict temperature changes and fluxes, obviously with the correct Equations of State as well as other pertinent information.

As it is well known, the results obtained using the hydrocodes have to be checked by test results in the validation process and in order to calibrate models for future use. The effect of C/D materials in accidental explosions can be devastating. There have been several accidents involving this type of materials and they have shown the danger at which operators are exposed especially in the manufacturing and processing of propellants and pyrotechnics. We believe hydrocodes can provide better tools in the prediction of damage from accidental explosions of 1.3 C/D materials, and also in our effort to provide personnel protection to the people involved with these materials.

References

1.- AUTODYN2D Users Manual, Century Dynamics, Inc. 1993.

2.- DOD 6055.9-STD, DOD Ammunition and Explosives Safety Standards, Assistant Secretary of Defense (Production and Logistics), U.S. Department of Defense, Washington DC, 1992.

3.- Spencer, A.J.M. Continuum Mechanics. Longman Scientific and Technical, 1988.

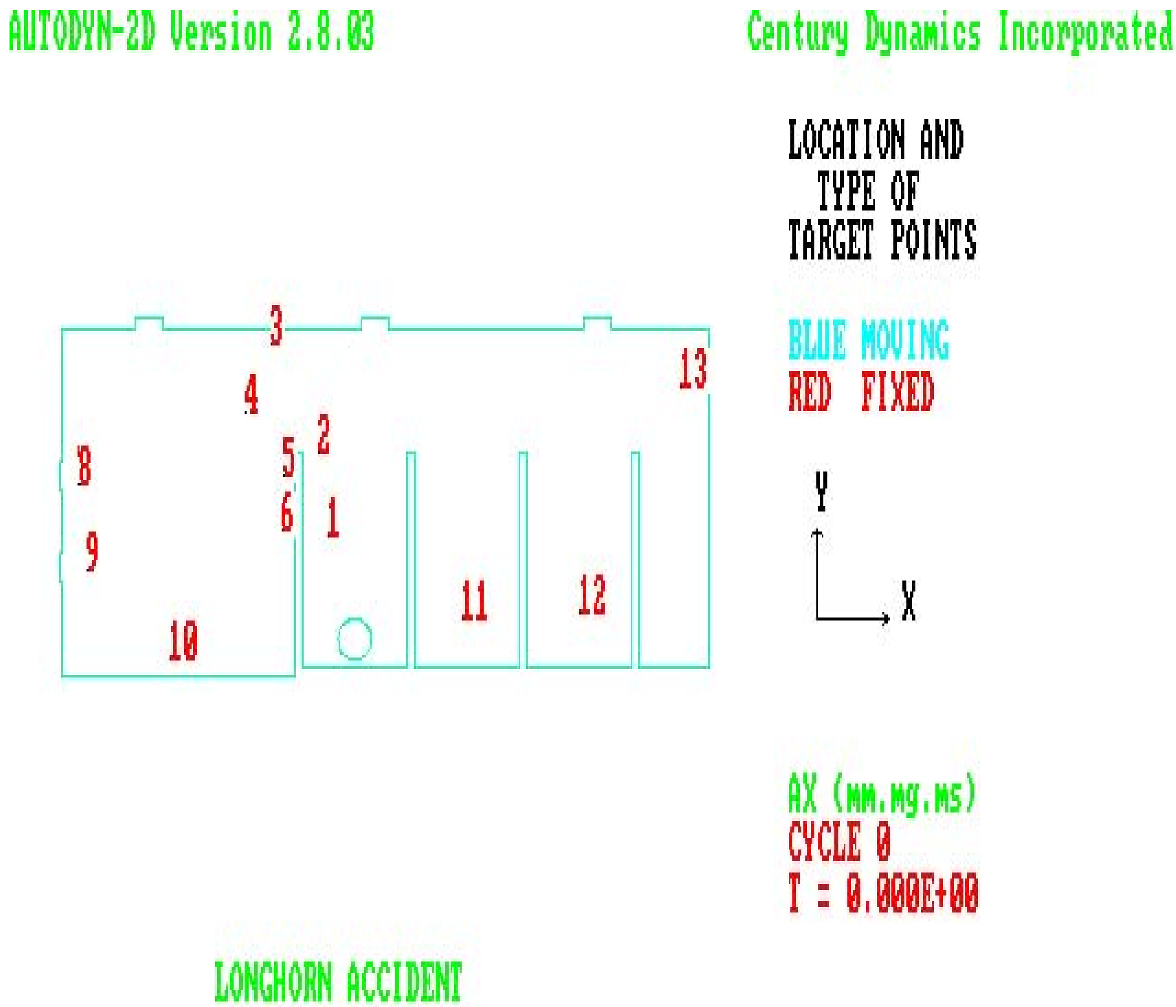
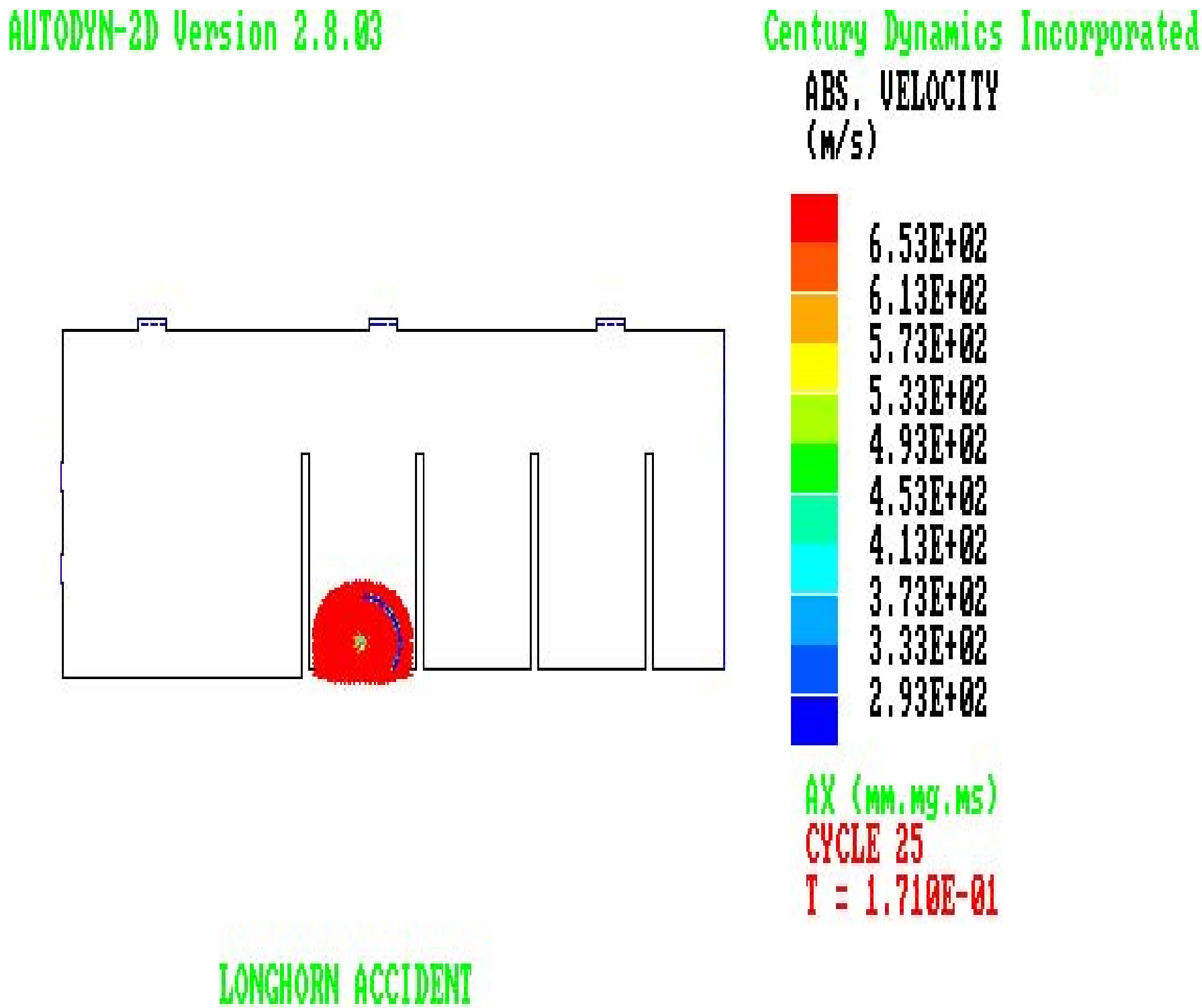

AUTODYN-2D Version 2.8.03
Century Dynamics Incorporated
LOCATION AND
TYPE OF
TARGET POINTS
BLUE MOVING
RED FIXED
Y
X
3
4
2
5
6
1
8
9
10
11
12
13
AX (mm.mg.ms)
CYCLE 0
T = 0.000E+00
LONGHORN ACCIDENT

Figure 1


AUTODYN-2D Version 2.8.03
Century Dynamics Incorporated
ABS. VELOCITY
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6.13E+02
5.73E+02
5.33E+02
4.93E+02
4.53E+02
4.13E+02
3.73E+02
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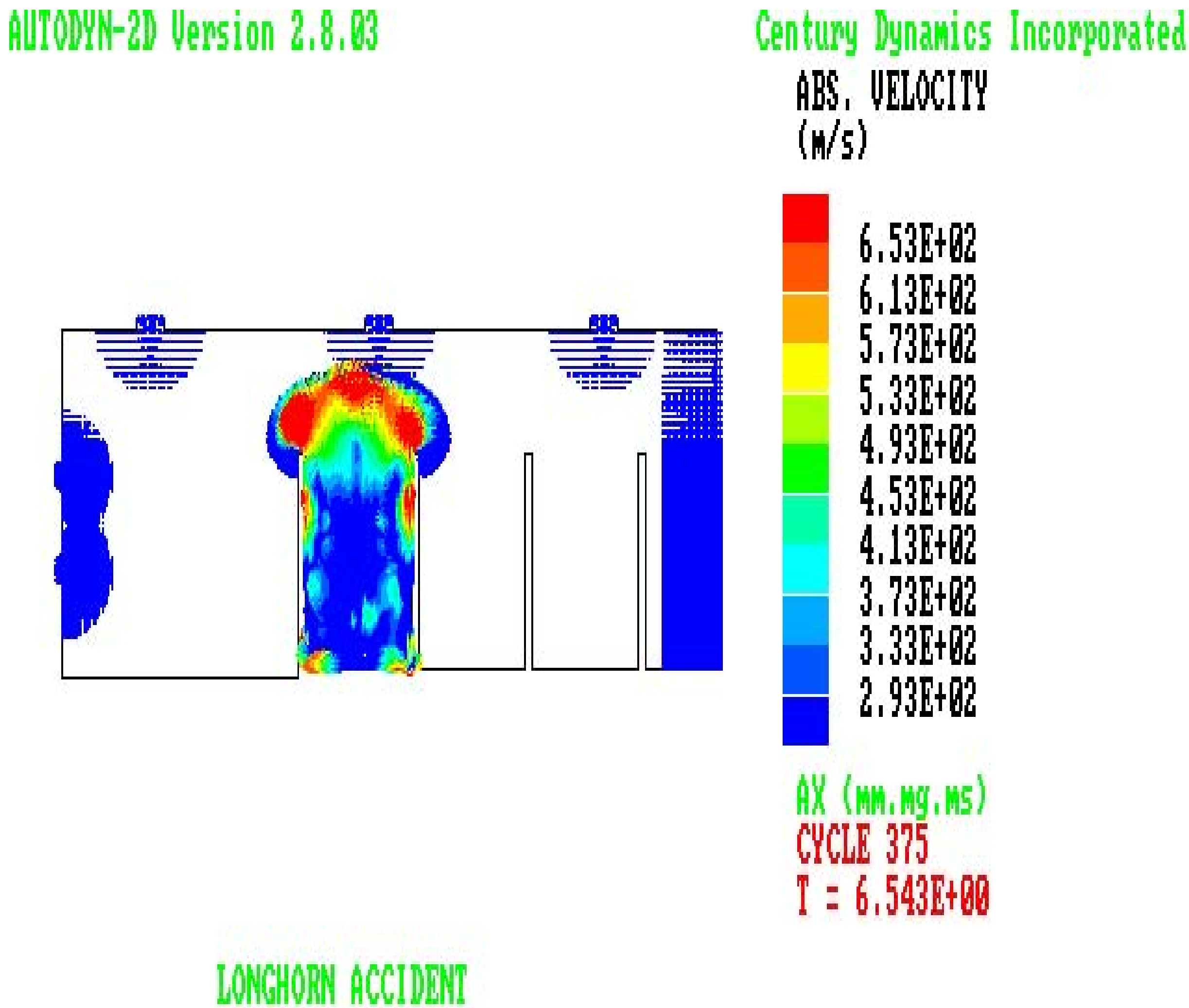
AX (mm.mg.ms)
CYCLE 25
T = 1.710E-01
LONGHORN ACCIDENT

Figure 2


AUTODYN-2D Version 2.8.03
Century Dynamics Incorporated
ABS. VELOCITY
(m/s)
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6.13E+02
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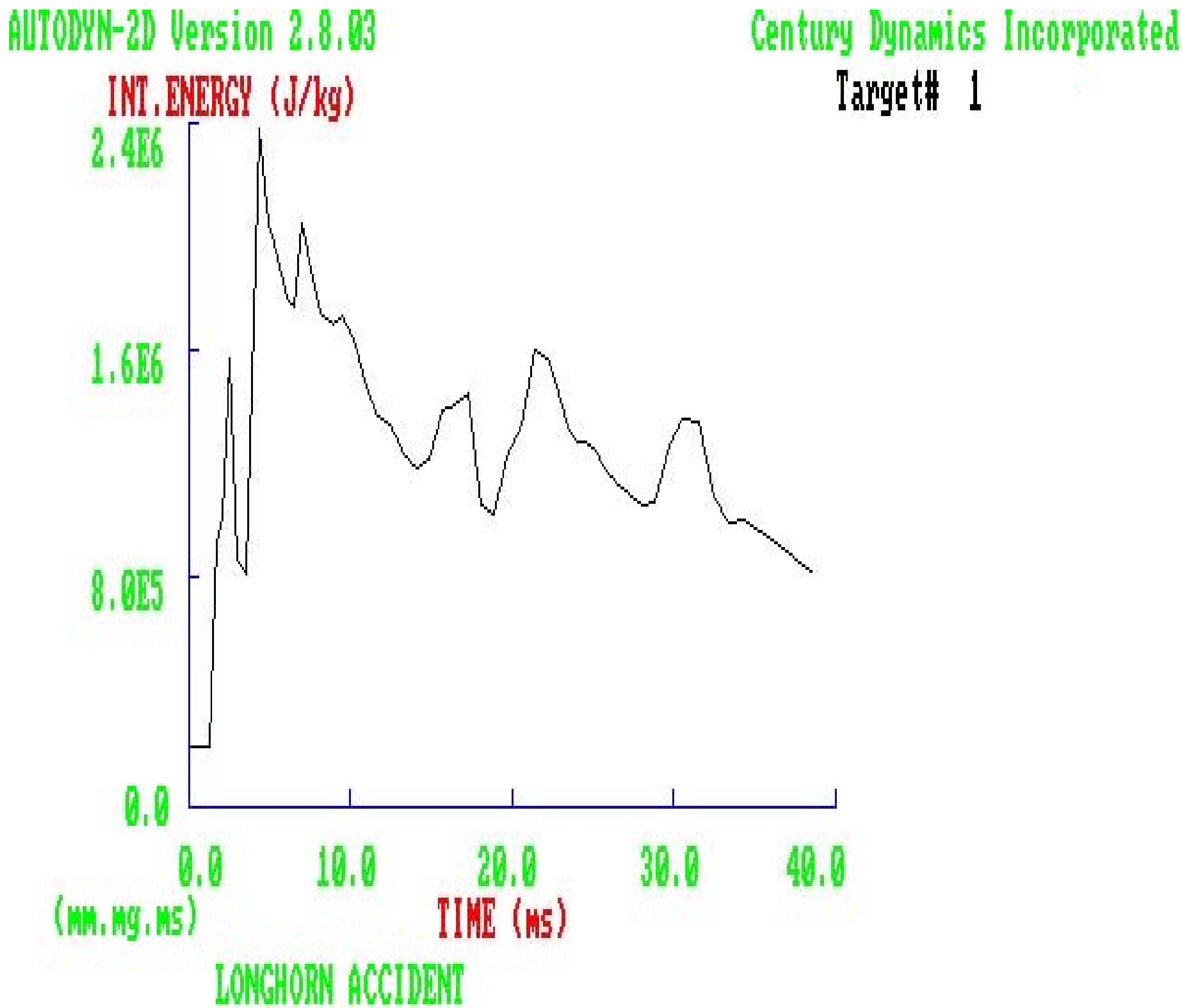
4.53E+02
4.13E+02
3.73E+02
3.33E+02
2.93E+02
AX (mm.mg.ms)
CYCLE 375
T = 6.543E+00
LONGHORN ACCIDENT

Figure 3


AUTODYN-2D Version 2.8.03
Century Dynamics Incorporated
INT.ENERGY (J/kg)
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1.6E6
8.0E5
0.0
0.0
10.0
20.0
30.0
40.0
(mm.mg.ms)
TIME (ms)
LONGHORN ACCIDENT

Figure 4

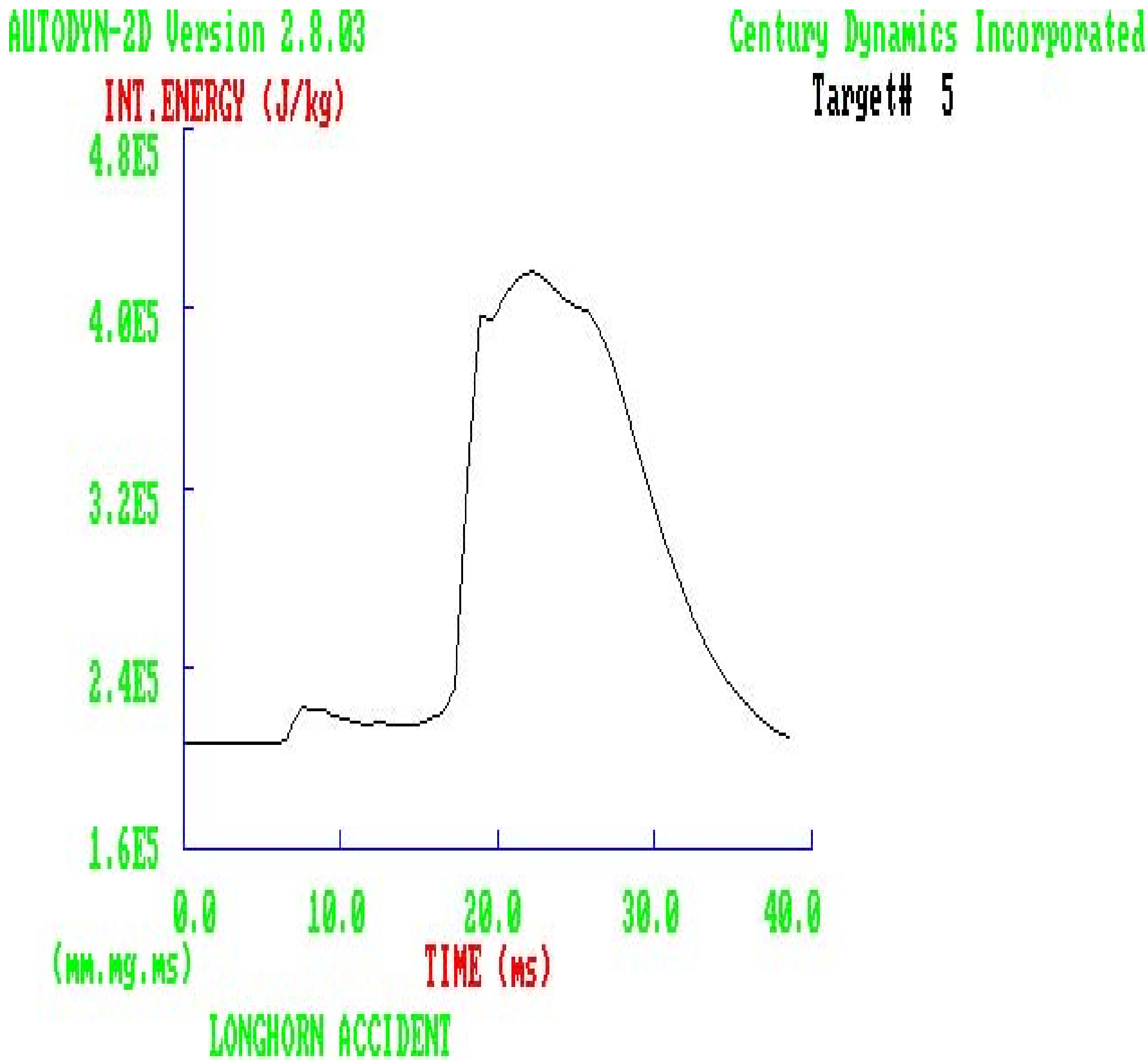

AUTODYN-2D Version 2.8.03
Century Dynamics Incorporated
INT.ENERGY (J/kg)
Target# 5
4.8E5
4.0E5
3.2E5
2.4E5
1.6E5
0.0
10.0
20.0
30.0
40.0
(mm.mg.ms)
TIME (ms)
LONGHORN ACCIDENT

Figure 5

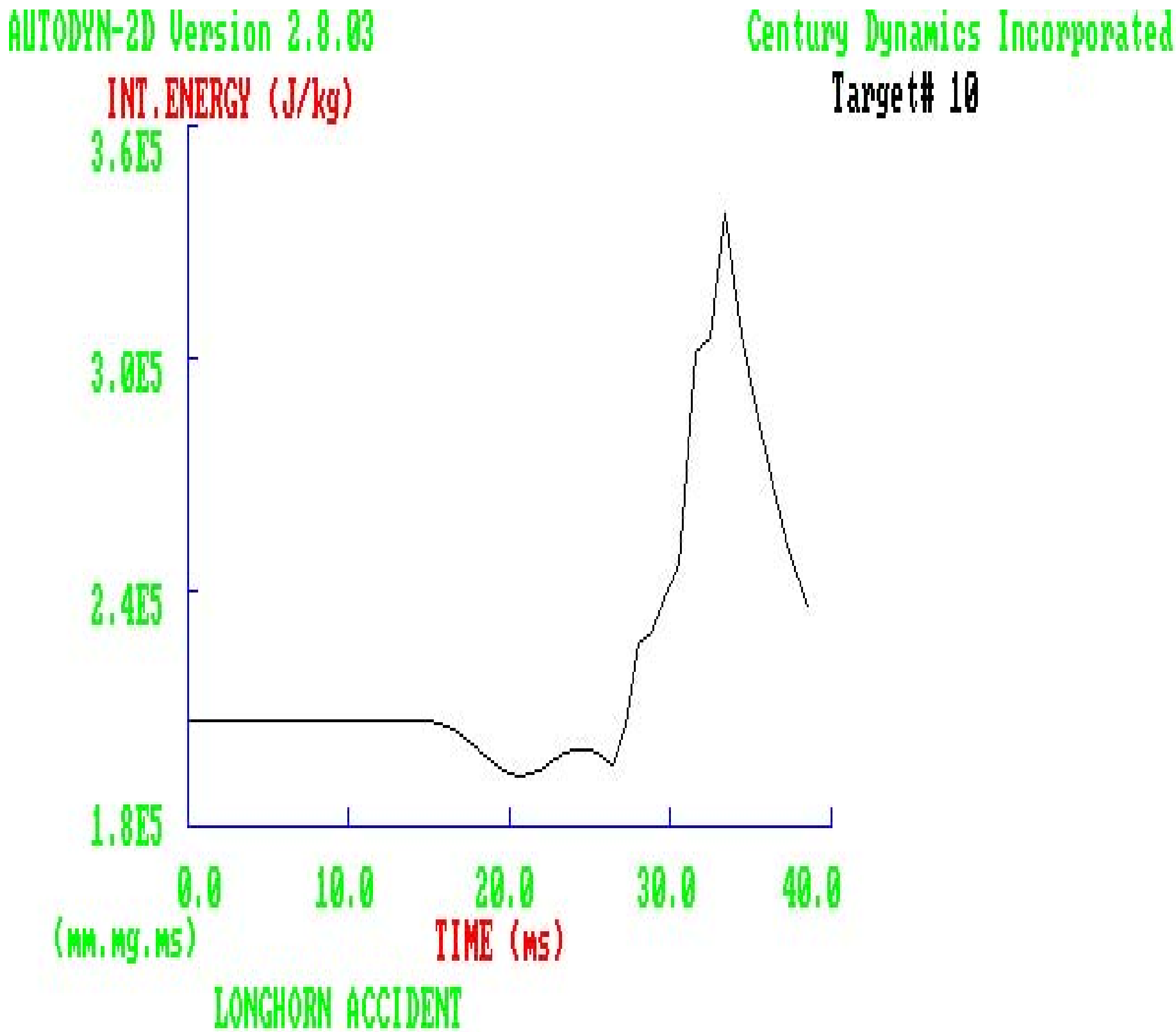

AUTODYN-2D Version 2.8.03
Century Dynamics Incorporated
INT.ENERGY (J/kg)
Target# 10
3.6E5
3.0E5
2.4E5
1.8E5
0.0
10.0
20.0
30.0
40.0
(mm.mg.ms)
TIME (ms)
LONGHORN ACCIDENT

Figure 6

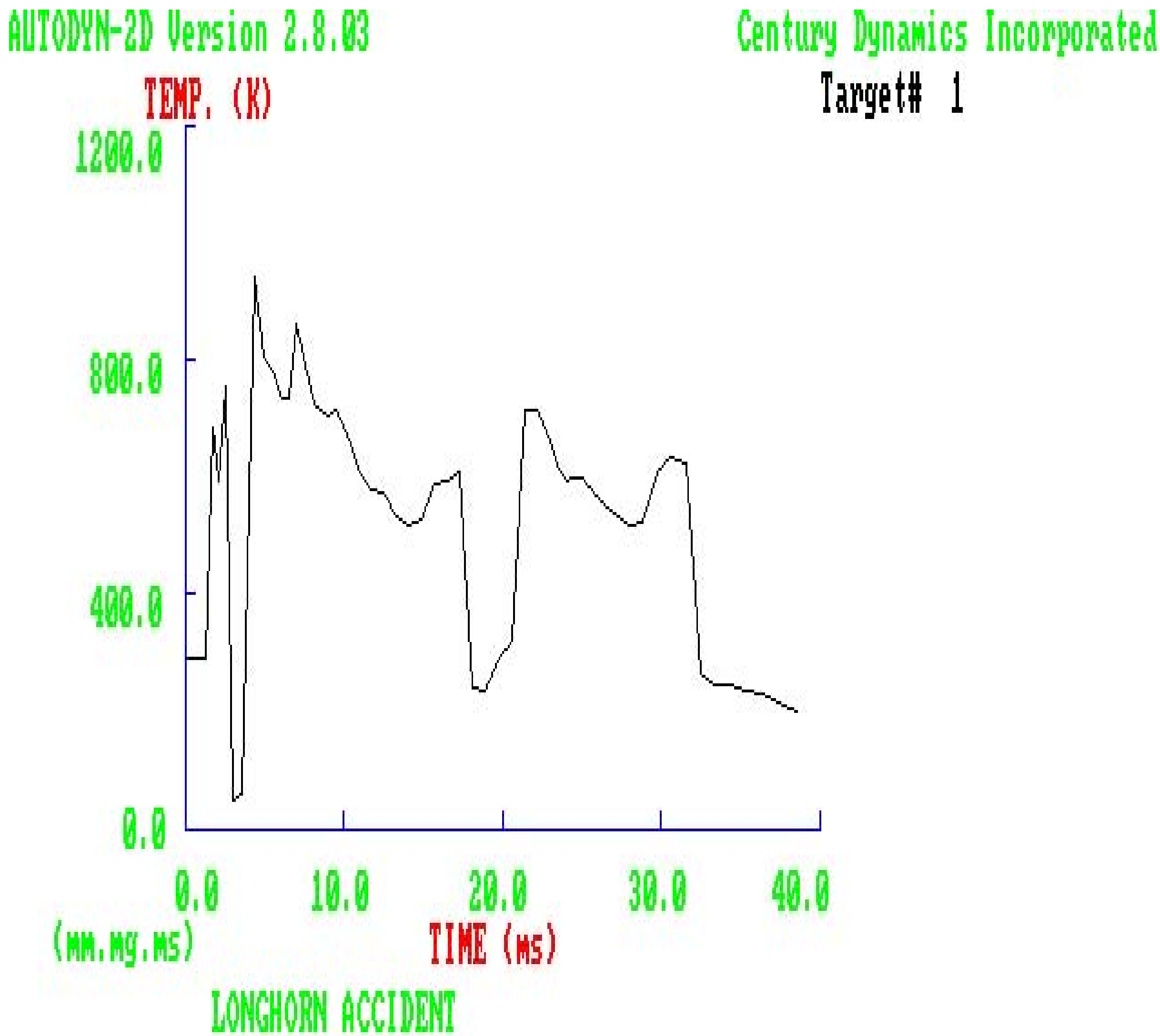
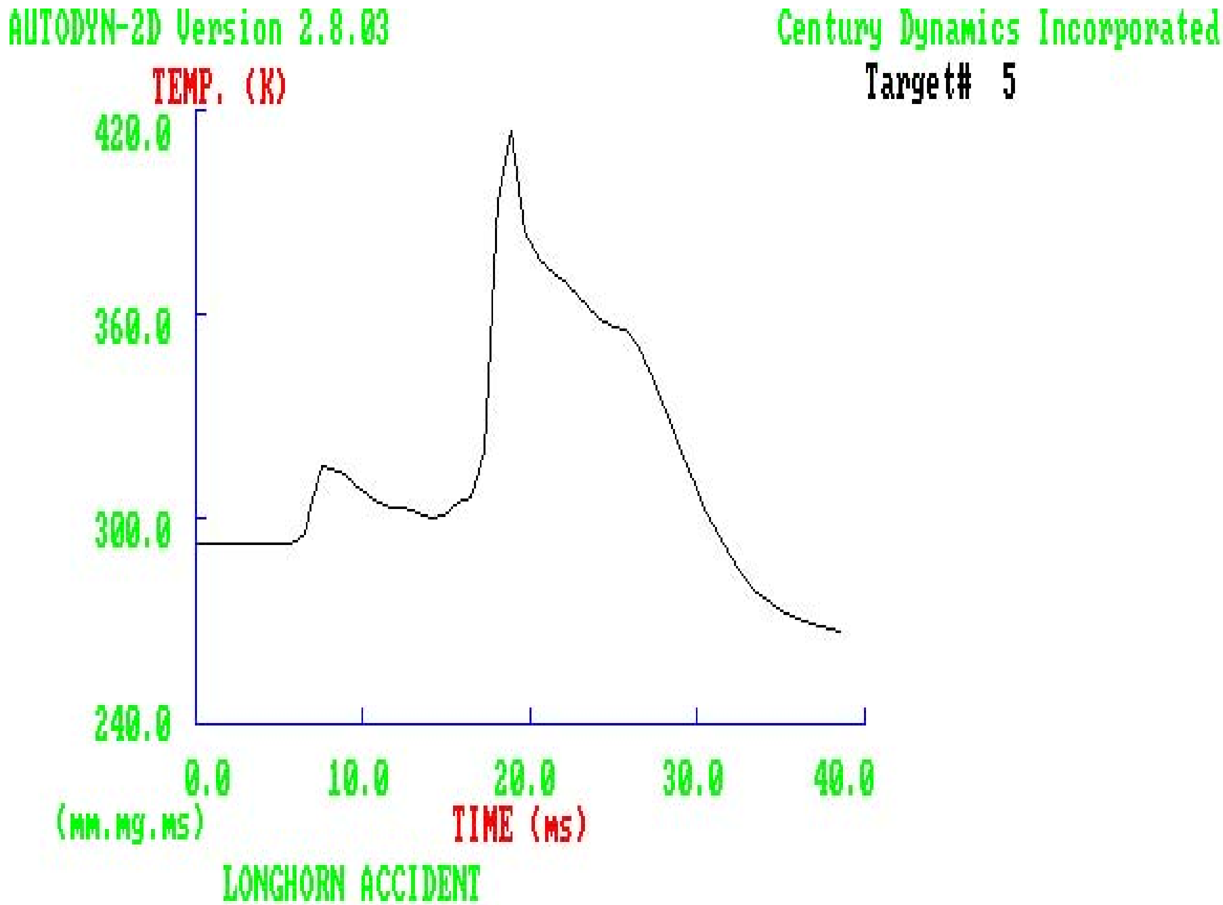

AUTODYN-2D Version 2.8.03
Century Dynamics Incorporated
TEMP. (K)
Target# 1
1200.0
800.0
400.0
0.0
0.0
10.0
20.0
30.0
40.0
(mm.mg.ms)
TIME (ms)
LONGHORN ACCIDENT

Figure 7


AUTODYN-2D Version 2.8.03
Century Dynamics Incorporated
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Target# 5
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300.0
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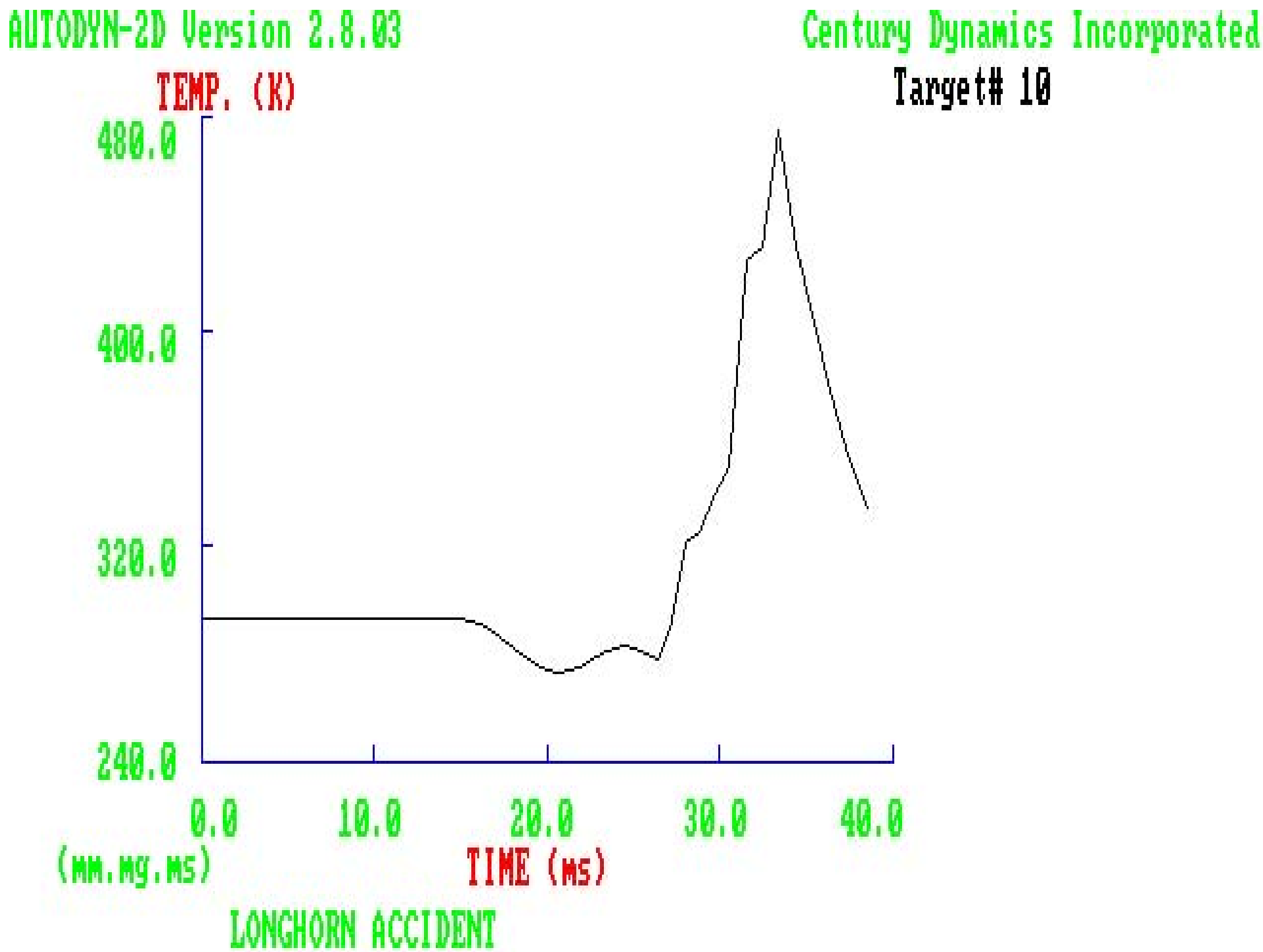
10.0
20.0
30.0
40.0
(mm.mg.ms)
TIME (ms)
LONGHORN ACCIDENT

Figure 8


AUTODYN-2D Version 2.8.03
Century Dynamics Incorporated
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Target# 10
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320.0
240.0
0.0
10.0
20.0
30.0
40.0
(mm.mg.ms)
TIME (ms)
LONGHORN ACCIDENT

Figure 9